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Microscopic Analysis of Fractured Dental Implant Surface after Clinical Use

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Abstract

Fractured implants can cause significant problems for both clinicians and patients, although they are fortunately rare. The major cause of fractured implant may be a fatigue fracture. To investigate how to increase the fatigue life and corrosion resistance of dental implants, the surface morphology of fractured implants were analyzed after clinical use. The period of surgical implantation after loading in patient jaws varied between a several months and years. Four fractured implant systems collected from Chosun Dental Hospital after clinical use. Three abutment screws and one fixture were used in this study with FE-SEM (field emission scanning electron microscope) after washing 5 minutes to remove debris with ultrasonic cleaner. Three of four samples were fractured at abutment screw valley formed keen-edged shape. In the cases of abutment screw fractures, two samples were fractured at the first thread of screw and one sample at the third thread of screw. The other one sample was fractured at thread of fixture. Fractured fixture was analysed with cross-sectional fracture surface and longitudinal fracture surface both. From observation of fatigue striations, it is possible to predict the life time of fractured implants and estimate the cleavage fracture and dimple fracture of implants.

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Keywords: Dental implant, Fatigue fracture, FE-SEM, Fatigue striation, Abutment screw

1. Introduction

Dental implant has applied as a alternative treatment method for the prosthodontic restoration of partial or full edentulous patient. Zarb and Schmitt [1] reported 11%, and Quirynen and Listagarten [2] reported 6% of the failure rate. Over the last decades, in spite of over 90% of success rate of dental implants have been reported, failures do occur with dental implants and attention must be paid to the factors of implant failure. Under physiological conditions, failures of osseointegration implants are mainly due to following complicated factors complex with physiology and physical properties of material which implant made of: 1) poor quality of bone [3], 2) lack of initial stability [4], 3) excessive loading [5], 4) loosening or fracture of screw [6-7], 5) fracture of implants.

Fracture of implant is one of the most frequently occurring mechanical factors of dental implant failure after successful osseointegration. When implant fractures occur, for the patient and clinician, most serious problem is to

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remove fractured implant. In spite of many researches offered many-side view for the causes and essential mechanism of implant fracture, it has not been definitely elucidated. Overload has been indicated as one cause factor of implant fractures. Balshi et al. [8] reported that physiologic or biomechanical overload results in implant fractures. Garallo-Albiol et al. [9] and Rangert et al. [10] suggested that mechanical overload which exceeded the resistance limit led metal fatigue and then fracture occurred. Conversely, Linkow et al. [11] insisted that implants fractures due to loading was caused by fatigue, not by excessive loading. Morgan et al. [12] also presented that not overload, but fatigue surrounding the implant fixture that accompanies marginal bone resorption occurred fractures of implants. On the other hand, Piatteli et al. [5] and Lee et al. [13] reported that developing of implants fractures was due to fatigue or traumatic overload. Choe et al. [14] reported that the major cause of a fractured implant may be corrosion fatigue fracture. Those studies propose the fatigue of metallic materials, which implants made of, as one of the most effective causes factors of fractured implants.

From a metallic materials point of view, concerning Ti implant that has been used widely a implant materials, nonetheless the chemical stability and resistance to corrosion of the oxidation film, Ti ion of titanium implant becomes a reason of its failure due to the acceleration of corrosion by the elution of ions from the planted implant surface and the induction of the fracture of implants that support load which interferes osseointegration. Many studies examined for the cause of fractured implants were performed in quasi-physiological environment or in animals.

Therefore, by performing the surface analysis of implants that were clinically functional for from several months to several years and subsequently removed for various reasons, our study leads up to clear the cause of implant fracture and improves in successful use the implant for a long period of time. In this study, a field-emission scanning electron microscope (FE-SEM) was used for analysis of surface of fractured implants.

2. Materials and Methods

2.1. Materials

To analyze the fracture surface of clinically used dental implant, in our study, 4 fractured dental implants which were removed from patients in Chosun Dental Hospital were collected. Sample 1, Sample 2 and Sample 3 were fractured at abutment screw of implant system, which consists of fixture, abutment and abutment screw. Sample 1 and Sample 2 were removed from the same patient. Sample 1 was settled to the position of right maxillary 1st molar April, 1999, removed June 2007 due to fracture of the screw, and was exchanged to gold screw, which was sample 2. Sample 2 was settled in June 2007 and removed March 2008 since screw fracture occurred. Sample 3 was positioned at left maxillary 1st molar and implanted September in 2008. Because of screw fracture, Sample 3 was eliminated from the patient in June 2010. In contrast with the cases of sample 1, 2 and 3, in the case of sample 4, the fixture was fractured when September 2009, which was implanted at the position of right maxillary canine in April 2006.

2.2. Methods

2.2.1. Scanning electron microscopic examination for fractured surface

In this study, for examination of fractography of the fractured implant, a field-emission scanning electron microscopy (FE-SEM;S-4800, Hitach, Japan) was used. FE-SEM has a super high resolution capacity and the characteristic of high resolution than other scanning electron microscope. Before used by FE-SEM, all implants were cleaned in liquid soap and washed for 5 min in acetone using ultrasonic cleaner. The surface of fracture was investigated via FE-SEM (S-4800, Hitach, Japan) at magnifications of up to ×30, ×200, ×1,000 and ×2,000. Avoiding contamination of the fractured surface, it needs to take care not to touch the fracture surface of samples.

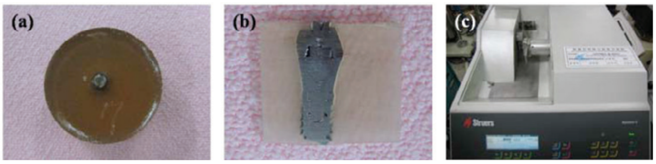

Fig. 1. Sample 4 (a) embbeded in epoxy resin, (b) middle section of longitudinal direction and (c) high speed precision cut-off

The other part of sample 4 was embedded in epoxy resin (Fig.1.a) and cut into 3 position of it along the longitudinal direction of the fixture axis used by high speed precision cut-off (Accutom-5, Struers, Denmark) (Fig.1.c). Middle section of sample 4 (Fig.1.b) was used for analysis longitudinal surface of fracture.

3. Results and discussion

The static fracture instantaneously occurs when over yield strength of force is applied and is related to overload. The dynamic fracture can occur when strain, which is lower than yield strength, is applied repeatedly. Fatigue fracture is sort of dynamic fracture and is defined as a phenomenon that, although a material is sufficiently stable under a static stress condition with no possibility of fracture occurring, crack propagation and fracture can occur with repeated or cyclic stress. When the plastic formation in metals continuously does occur, fracture of metal eventually happen and fractured surfaces of implants have appearance of two types; ductile and brittle. Ductile fracture usually shows rough facet consisted of dimple and brittle fracture occurs with less plastic deformation and shows smooth and flat facet.

3.1. Surface of fractured abutment screws

Fig. 2 shows fracture patterns of a screw taken from the case of sample 1. Sample 1 is the abutment screw fractured after 98 months use (1999.4~2007.6). Fracture of sample 1 occurred at the valley of 1st thread of the abutment screw. It seems, according as the starting point of the fracture that the fracture initiated at and propagated from the left side on the Figure (Fig.2.a). In magnified images of Fig. 2.a, obvious honeycomb-shaped dimple pattern and plastic deformation were detected (Fig. 2). This figure indicates that dimple pattern was formed by overload effecting vertically to fracture surface. Dimple pattern and plastic deformation are representative characteristics of ductile fracture surface. Ductile fracture indicates the causes of fracture were due to inappropriate design or overload, not physical properties of metallic materials or a fault of proceeding for material manufacture. Park et al.[15] insisted plastic permanent deformation of the implant screw results, if a bending force on the implant restoration causes overload larger than the yield strength of the screw.

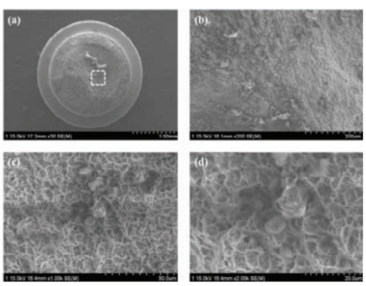

Fig. 2. FE-SEM showing the fracture surface of sample 1, fractured abutment screw, magnified up to (a) ×30, (b) ×200, (c) ×1,000 and (d) ×2000

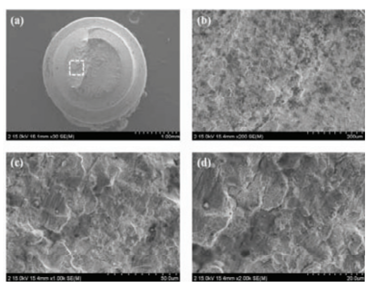

Fig. 3. FE-SEM showing the fracture surface of sample 2, fractured abutment screw, magnified up to (a) ×30, (b) ×200, (c) ×1,000 and (d) ×2000

Fig. 3 shows fracture patterns of an abutment screw from the case of sample 2. Sample 2 was settled after sample 1 fractured, in the same patient who is the case of sample 1, and fractured again 9 months after (2007.6~2008.3). Sample 2 shows different surface pattern compare with sample 1. Fracture of sample 2 occurred at the valley between 2nd and 3rd thread of the abutment screw. Fig.3.a shows overall fracture surface in which the fracture initiated at and propagated from the top left side of figure. This figure, showing beach mark detected on left upper side, has fatigue fracture process and final ductile fracture. Slip band is detected and indicated that the cause of the fracture was cyclic load (Fig. 3.c, d). Slip bands are known as a starting point of crack initiation. Slip bands are formed when the surface receives high cycle fatigue, fatigue life over 10^4~10^5 cycles. The fatigue striations are also clearly detected as shown in Fig. 3 and small spacing of striations is presented, suggesting fatigue crack formed by a lower propagation rate. From these results, in the case of sample 2, fatigue phenomena were observed. According to Morgan et al. [12] the striations were the pathognomonic mark of fractures resulting not from overload, but from fatigue failure and were explained as the portion of the implant that remained in the bone always showed a very high percentage of bone-implant contact.

The patient, whom fractures of sample 1 and 2 occurred to, had many past dental history to torque loosening screw during the abutment screw of sample 2 was settled and to eliminate lateral force by occlusal adjustment. Screw fracture may result from metal fatigue after screw loosening. Two mechanism of screw loosening have been studied [16]: excessive bending causes overload larger than the yield strength. The other mechanism of screw loosening is based on the fact micro-movements occur between the surfaces, when the screw interface is subjected to external loads. Schwarz [17] suggested that occlusal forces are magnified by the long lever arm to the abutment-fixture interface which is located at the alveolar crest, and then the abutment screw most frequently fractured. The screw of sample 1 is composed of titanium, and the screw of sample 2 is a gold screw that titanium coated with gold. In this patient, titanium screw was used for long-term (98 months) compared to gold screw (9 months) due to screw loosening according to clinical decision, on the contrary, Laney et al. [18] reported that the gold abutment screws remained more secure than titanium screws due to use of slightly oversized gold screws which eliminate the problem of recurring screw loosening. It is confirmed that screw loosening can be a major factor of decreasing the life of abutment screw.

The case of sample 3, as in the case of sample 1, the valley of the 1st thread of abutment screw was fractured after 21 months (2008.9~2010.6) clinically used. On overall surface of fracture, the lower left corner was starting point of fatigue fracture initiation (Fig.4.a). Beach mark is detected (Fig.4.a) and fatigue striation is also ascertained in Fig.4.c and d. Flat facet, belong fatigue striation in Fig. 4.b, is supposed as facet due to forming by wear during fatigue fracture. Hence, fatigue fracture was suggested as one of causes of fracture in the case of sample 3.

In radiography of sample 3 patient, peri-implant bone resorption was detected (Fig.5.a, b). The complex factors with bone resorption and cyclic load induce implant fracture. Morgan et al. [12] suggested that coronal bone resorption produces a higher bending stress of implant and supported by Rangert et al. [10] study; peri-implant bone resorption produced by high load and an increased bending moment on the implant has been found before implant fracture.

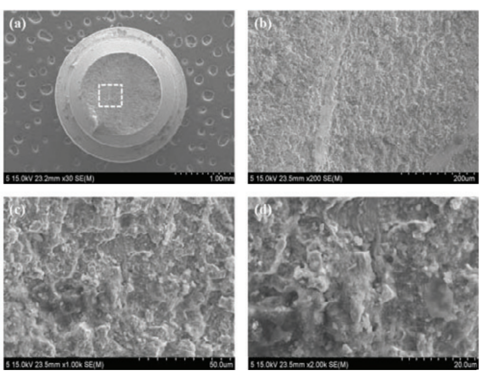

Fig. 4. FE-SEM showing the fracture surface of sample 3, fractured abutment screw, magnified up to (a) ×30, (b) ×200, (c) ×1,000 and (d) ×2000

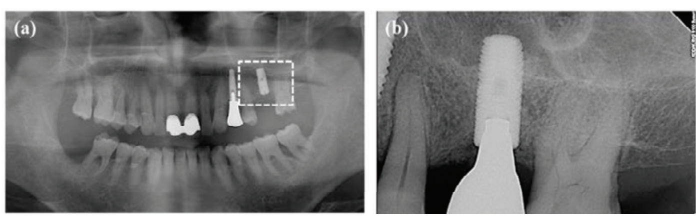

Fig. 5. Radiography of sample 3; (a) a panoramic view, (b) a standard view.

3.2. Surface of fractured fixture

3.2.1. Cross-sectional surface of fractured fixture

Fig. 6 shows fracture patterns of fixture taken from sample 4. According as the starting point of fracture, the fracture initiated at and propagated from the right side on the Fig.6.a. In enlarged images, the fatigue striation and plastic deformation, which was formed by a compressive force on fracture surface after fracture occurred, appear (Fig. 6.b, c, and d).

The implant of sample 4 was planted at the position of right maxillary 1st premolar in May, 2005. But, because of bad quality of peri-implant bone, implant was removed and replanted at the position of canine in April, 2006. After 41 month (2006.4~2009.9), fixture was fractured at the valley of the thread mating with peri-implant bone level (Fig. 7). With regard to the topic on cause of fractured implants, it is important whether bone loss is presented. A root of

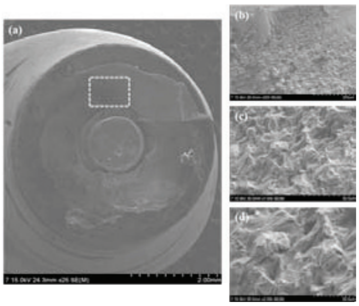

Fig. 6. FE-SEM showing the fracture surface of sample 4, fractured fixture magnified up to (a) ×30, (b) ×200, (c) ×1,000 and (d) ×2000

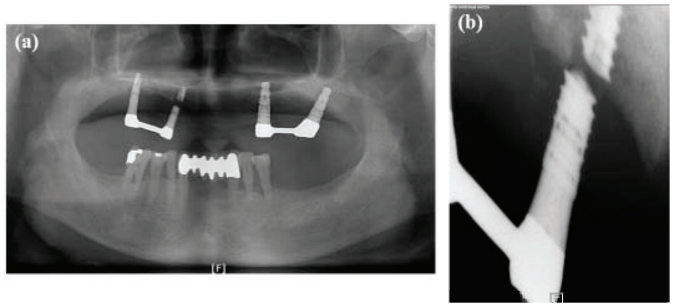

Fig. 7. Radiography of sample 4; (a) a panoramic view, (b) a standard view.

thread with the initial crack formation produce a area of stress concentration [12] and the cracks propagate from the site of maximum stress with fatigue striation and can produce a sudden failure [19]. Considering the fixture fractures, the incidence of fractures increases the longer the fixtures are loaded, demonstrating that metal fatigue and subsequent fracture is a time-dependent phenomenon [17]. Rangert et al. [10] and Balshi et al. [8] insisted that implant fixture fractures have occurred with a prosthesis supported by one or two implants in combination with cantilevers and bruxism or heavy occlusal forces, leading to bending overload.

3.2.2. Longitudinal surface of fractured fixture

Fatigue crack is started at the position of cross-sectional crack and vertically propagated (Fig. 8b). This phenomenon supported by study of Piattelli A. et al.[20] which suggested that the existence of parafunctional activity such as bruxism and bone loss have been described as etiological factors that generates mechanical overload directly related to crack initiation of implant fracture. But the parafunctional activity has not been recorded in past dental history of the patient of sample 4. The stages of fatigue fracture are divided to 3 stages [21]: propagation of crack that is the growth of small cracks in the area of stress concentration, which is thought to be the area of fixture mating with peri-implant bone in this case, the propagation of crack that is a small advancement of crack in each cyclic load which received to parallel direction of implant axis, and upon the advanced crack reaching a critical size, very rapid fracture.

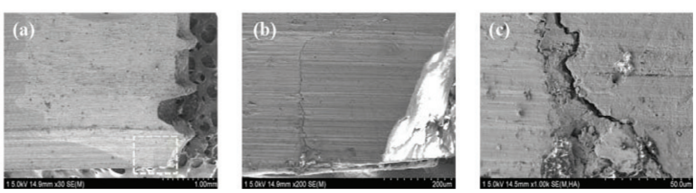

Fig. 8. FE-SEM showing the longitudinal fracture surface of sample 4, fractured fixture, magnified up to (a) ×30, (b) ×200, and (c) ×1,000

4. Conclusions

The surface of fractured implants after clinical use was examined by the FE-SEM and the following results were obtained. The surface of a fractured abutment screw from sample 1, dimple pattern and plastic deformations was detected. And it is thought to be because of overload. The surface of a fractured abutment screw from sample 2, beach marks and slip bands were detected and indicated that cyclic load inducing fatigue failure results in screw fracture. The surface of a fractured abutment screw from sample 3, because of cyclic load and peri-implant bone resorption, beach marks and fatigue striations were formed on the surface of fracture. Fracture surface of fixture, in the case of sample 4, also shows fatigue striation at cross-sectional surface. Longitudinal surface of fractured fixture shows that the cyclic load, occurring fatigue fracture, had been received to parallel direction of implant axis. The fractured part was related with the peri-implant bone level and bone resorption after clinical use.

Acknowledgements

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